

Hall Sensor

1. General

The Hall sensor (element) is a magneto-electric transducer which has attracted popular attention in recent years as a position sensor or a electronic switch in application ranges such as small DC (brushless) motors, automotive use, and instrumentation equipment.

And it enables conversion from mechanical to electronic switching and from brushed to brushless motor, and the production of noiseless high-performance units, so it is expected to be applied over a very wide application range in both consumer and industrial fields in near future.

The materials and features of commercialized Hall Sensor at present are shown as follows.

And the material of Toshiba Hall Sensor is GaAs.

Table 1

Type of Hall Sensors	Characteristics of elements
GaAs Hall sensor	<ul style="list-style-type: none"> (1) Temperature coefficient of V_H is very small with constant current operation (wide bandgap; 1.43 eV). (2) Temperature coefficient of V_{HO} is small with constant voltage operation. (3) Linearity of V_H to magnetic flux is excellent. (4) Input resistance is not changed by current or magnetic flux.
InAs Hall sensor	<ul style="list-style-type: none"> (1) Temperature coefficient of V_H is small with constant current operation. Other characteristics are situated between those of GaAs and InSb sensors.
InSb Hall sensor	<ul style="list-style-type: none"> (1) High output is possible (electron mobility μ_n is very high: $75,000\text{cm}^2/\text{sec}$). (2) V_H varies less against temperature changes with constant voltage operation (however, inferior to GaAs sensors). (3) V_H varies greatly against temperature changes with constant current operation. $\frac{V_H(T=50^\circ\text{C})}{V_H(T=25^\circ\text{C})} = 1/3 \sim 1/2$ V_H shows lapsed changes due to self-heating. (4) V_H becomes saturated near $B = 1\text{kG}$. (5) Input resistance varies depending on current and is internally modulated by a magnetic field.

As may be observed from the above remarks, it may be stated that InSb Hall sensors are suitable for digital application and GaAs Hall sensors for analog use.

As a matter of reference, Toshiba Hall sensors — high output voltage — are applicable for both digital and analog fields.

2. Hall effect

When applying a current I_c to a thin semiconductor element and applying a magnetic flux B in the vertical direction to it, voltage V_H is generated in a direction vertical to both the current and the magnetic flux. This phenomenon is the so-called Hall effect discovered by E. H. Hall in 1879.

The voltage V_H thus occurring, termed "Hall output voltage," is defined as —

$$V_H = \frac{R_H}{d} \cdot I_c \cdot B \cdot f_H \left(\frac{\ell}{W} \cdot \theta \right) \dots\dots\dots (1)$$

f_H in this equation is a design factor, substantially dependent upon the element design (ℓ/W) and the magnetic field. The larger both ℓ/W and B become, the nearer f_H is unity.

Assuming that

$$K_H = \frac{R_H}{d} f_H \left(\frac{\ell}{W} \cdot \theta \right)$$

$$V_H = K_H \cdot I_c \cdot B \dots\dots\dots (2)$$

Therefore, V_H is represented by the product of control current I_c and magnetic flux B .

K_H is termed product sensitivity, a constant to be determined according to the characteristics of the semi-conductor elements to be used.

Assuming that $K^* = \frac{K_H}{R_d}$ equation (2) is changed as follows:

$$V_H = K^* R_d \cdot I_c \cdot B \dots\dots\dots (3)$$

where, R_d is internal resistance of the element and K^* is specific sensitivity. The larger this value, the more excellent the output characteristics of the element.

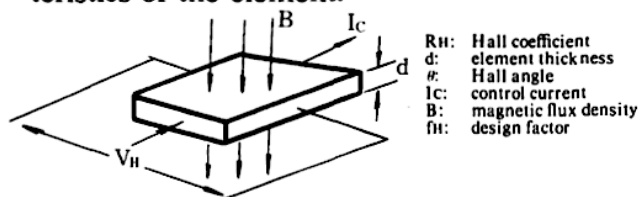


Fig. 1

3. Hall sensor driving methods

Hall sensor driving methods are constant-current and constant-voltage driving.

(1) Constant-current driving

In the case of constant-current driving, it is possible to get the Hall output voltage in proportion to the internal resistance of the element from equation (3). The temperature characteristics of the Hall output voltage are quite excellent for GaAs Hall sensors. ($V_{HT} = -0.06\%/^{\circ}\text{C}$, maximum). This is because the band gap of the actual GaAs is so large ($E_g = 1.43 \text{ eV}$) that the GaAs Hall sensors are highly stable thermally.

(2) Constant-voltage driving

In the case of constant-voltage driving of a Hall sensor, V_H is shown as follows from equation (3):

$$V_H = K^* \cdot V_c \cdot B \mid (R_d \cdot I_c = V_c \text{ [constant]})$$

The Hall output voltage is not related to internal resistance R_d of an element; thus, obtained is almost constant Hall output voltage. The deviation of specific sensitivity K^* is nearly $\pm 10\%$. When setting V_c it is necessary to set the control current $I_c (= V_c/R_d)$ against the minimum R_d , so that must not exceed over the maximum rating of I_c .

The temperature characteristics of Hall output voltage are one digit larger than those of the constant-current driving method because $V_{HT}(\text{constant-voltage drive})$ is approximately $-0.3\%/^{\circ}\text{C}$. This is because the temperature characteristics of Hall output voltage depend on those of electron mobility in the case of constant-voltage driving, while they depend on those of carrier concentration $n (= n_0 \exp(E_g/2KT))$ in the case of constant current driving.

4. Positioning accuracy of Hall sensors

(1) THS102A (H-Type)

The positioning accuracy of this Hall sensors is $\pm 0.15\text{mm}$ in both the X and the Y axes, assuming that the center of the Hall sensor is represented by the intersection point of the two diagonal lines A and B shown in Fig. 2.

(2) THS103A (SIP-Type)

The positioning accuracy of this type is shown in Fig. 3.

(3) A Hall sensor is mounted on the fourth terminal for the H-type or on the second terminal for the SIP-type; the operating layer is about 0.3mm above the terminal surface. (See Fig. 4)

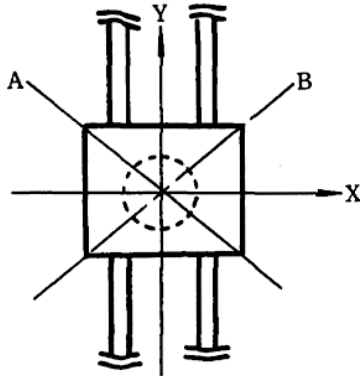


Fig. 2

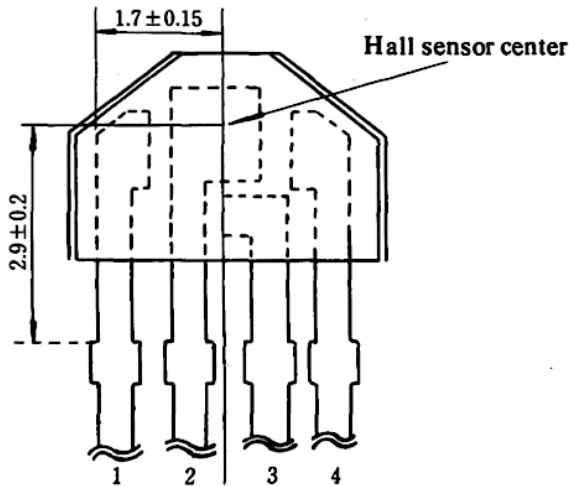


Fig. 3

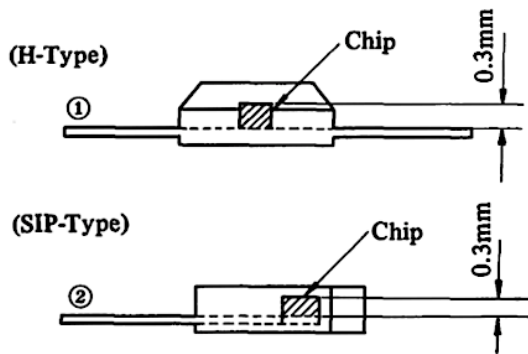


Fig. 4

5. Typical application examples

This section describes the use of a Hall sensor when using it for position sensing of rotors in a brushless motor.

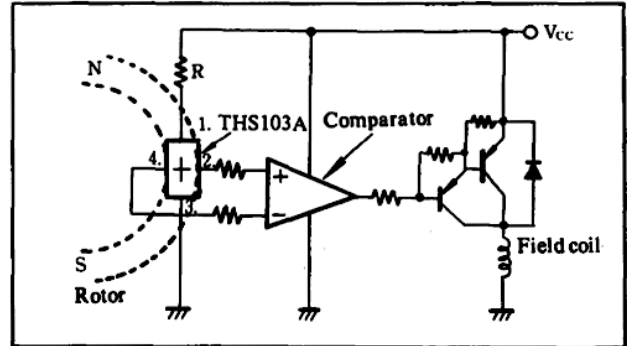


Fig. 5 Application circuit

Conditions:

- 1 The Hall sensor to be used in THS103A.
- 2 Flux linkage applied to the Hall sensor is the sinusoidal wave type; its peak value B_m is 0.8 KG.
- 3 Comparator offset voltage $V_{IO} = \pm 2$ mV.
- 4 Comparator output is the open collector type.
- 5 $V_{CC} = 12.0$ V.

Since the rated value of control current I_c of THS103A is 10 mA maximum, the value of series resistance R must be a value that satisfies $I_c \max. \geq V_{CC}/(R + R_{dmin.})$.

The range of internal resistance R_d of THS103A is $450 \sim 900 \Omega$; $R \geq 750 \Omega$. Therefore, $R = 910 \Omega$ is selected in this case.

Since the Hall output voltage $V_H = K_H \cdot I_c \cdot B = K \cdot R_d \cdot I_c \cdot B$,

$$V_H = K \cdot R_{d \min.} \cdot I_c \cdot B_m \sin \theta$$

for the minimum R_d , and

$$V_H = K \cdot R_{d \max.} \cdot I_c \cdot B_m \sin \theta$$

for the maximum R_d .

However, actual voltage evidenced at the output terminal of a Hall sensor is that to which residual voltage V_{HO} is added.

$$V_H = K \cdot R_d \cdot I_c \cdot B_m \sin \theta \pm V_{HO}$$

This residual voltage V_{HO} as well as the offset voltage of comparator V_{IO} are the major factors affecting turnoff timing of the field coil drive transistor — namely, the electric angle allowance.

Specific sensitivity K^* takes the following value in accordance with the relation between Hall output voltage V_H and element resistance R_d of THS103A. Since R_d and V_H have the linear relation, V_H is minimum when R_d is minimum (only under the constant-current condition).

Therefore, from the specifications of THS103A —

$$K^*_{\min.} = 50(\text{mV})/[5(\text{mA}) \times 450(\Omega) \times 1(\text{KG})] = 22.2 \times 10^{-3} (1/\text{KG})$$

$$K^*_{\max.} = 120(\text{mV})/[5(\text{mA}) \times 900(\Omega) \times 1(\text{KG})] = 26.7 \times 10^{-3} (1/\text{KG})$$

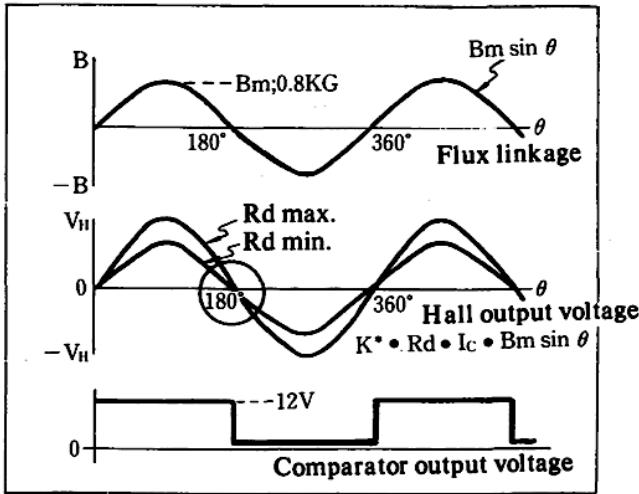


Fig. 6

The Hall output voltage of THS103A is —
 $V_{H\min.} = K^*_{\min.} \cdot R_{d\min.} \cdot I_c \cdot B_m \sin \theta \pm V_{HO}$
 $= 22.2 \times 10^{-3} \times 450 \times 8.8 \times 0.8 \sin \theta \pm V_{HO}$
 $= 70.3 \sin \theta \pm V_{HO}(\text{mV})$

$V_{H\max.} = K^*_{\max.} \cdot R_{d\max.} \cdot I_c \cdot B_m \sin \theta \pm V_{HO}$
 $= 26.7 \times 10^{-3} \times 900 \times 6.6 \times 0.8 \sin \theta \pm V_{HO}$
 $= 126.9 \sin \theta \pm V_{HO}(\text{mV})$

Figs. 6 and 7 below show the waveforms of flux linkage, Hall output voltage, and comparator output voltage.

Enlarged view of the encircled portion of Hall output voltage in the figure on the left

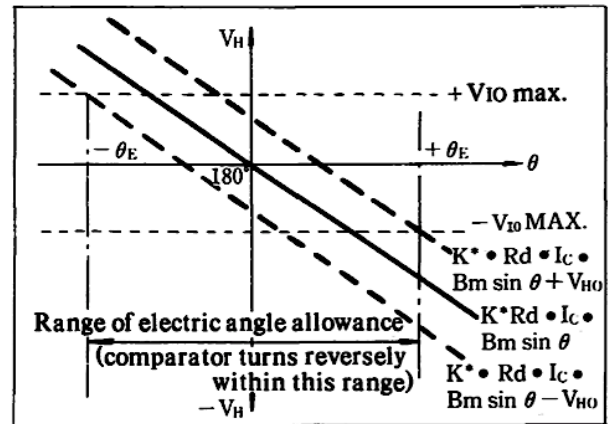


Fig. 7

The calculation of electric angle allowance is —

When R_d is maximum:

Since residual voltage V_{HO} is in linear proportion to control current I_c , the maximum value of V_{HO} (namely, $V_{HO\max.}$) is —

$$V_{HO\max.} = V_{H\max.} \cdot (V_{HO}/V_H)_{\max.} \cdot [I_c (\text{actually supplied})/I_c (V_{HO}/V_H \text{ measured})]$$

$$= 120(\text{mV}) \times 10(\%) \times 6.6(\text{mA})/5(\text{mA}) = 15.8(\text{mV})$$

Assuming the comparator output is reversed when the Hall output voltage V_H exceeds the offset voltage of the comparator.

$$-V_{IO\max.} = K^*_{\max.} \cdot R_{d\max.} \cdot I_c \cdot B_m \sin (180^\circ \pm \theta_E) + V_{HO\max.}$$

$$-2(\text{mV}) = 126.9 \sin (180^\circ \pm \theta_E) + 15.8 (\text{mV})$$

$$\therefore \theta_E = 8.06^\circ$$

When R_d = minimum:

In the same manner as above,

$$V_{HO\max.} = V_{H\min.} \cdot (V_{HO}/V_H)_{\max.} \cdot [I_c (\text{actually supplied})/I_c (V_{HO}/V_H \text{ measured})] = 8.8 (\text{mV})$$

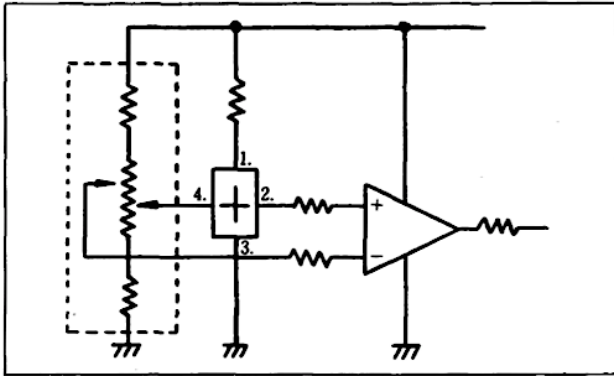
$$-V_{IO\max.} = K^*_{\min.} \cdot R_{d\min.} \cdot B_m \sin (180^\circ + \theta_E) + V_{HO\max.}$$

$$-2 (\text{mV}) = 70.3 \sin (180^\circ + \theta_E) + 8.8$$

$$\therefore \theta_E = 8.84^\circ$$

Therefore, if it is necessary to reduce the above-mentioned θ_E due to performance requirements of a motor, also it is necessary to increase the peak value of flux linkage or to suppress V_{HO} of a Hall element and offset voltage of the comparator.

Fig. 8 is a typical example of a V_{HO} compensating circuit for a Hall sensor.



The portion surrounded by the hyphenated line denotes the V_{HO} compensating circuit

Fig. 8

It is possible to reduce θ_E to zero by using the V_{HO} compensating circuit of a Hall sensor.

With reference to the residual voltage ratio of a Hall sensor (V_{HO}/V_H), it is possible to suppress θ_E by selecting the optimum offset voltage of a comparator.

In the actual design stage, consideration must be taken to variations of source voltage, variations of relevant constants to be caused by changes in ambient temperature, and positioning accuracy.

6. Precautions on handling

The enclosure of a Toshiba Hall sensor is designed very compactly in size to facilitate mounting onto small-scaled equipment. Pay heed to the following points when actually mounting these sensors.

Stress on electrode leads

Be careful not to supply 500g or more force to the leads.

Bending electrode leads

- 1) Prior to bending electrode leads, secure the lead side in position so that excessive force is not applied between molded resin parts and the lead wires.
- 2) Bend the leads at a point 1mm or more apart from their roots (molded end).
- 3) Do not repeat bending and stretching the leads.
- 4) Avoid bending the leads on their thicker side.

Mounting on a circuit board

- 1) When using an adhesive agent to secure an element, select an agent which will not

adversely affect the element.

- 2) When soldering a Hall sensor on a circuit board, it is recommended using rosin flux with low corrosiveness and high insulating capability.

Due care must be exercised as to SIP-package Hall sensors, since the distance between leads is small.

- 3) Solder the lead wires at 260°C or less for 10 seconds or less.

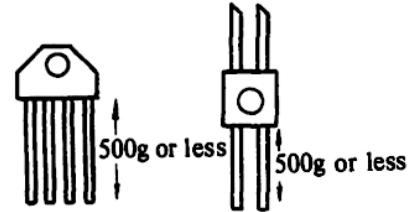


Fig. 9

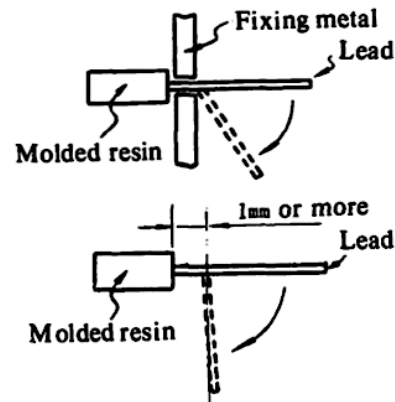


Fig. 10

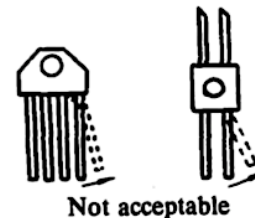


Fig. 11

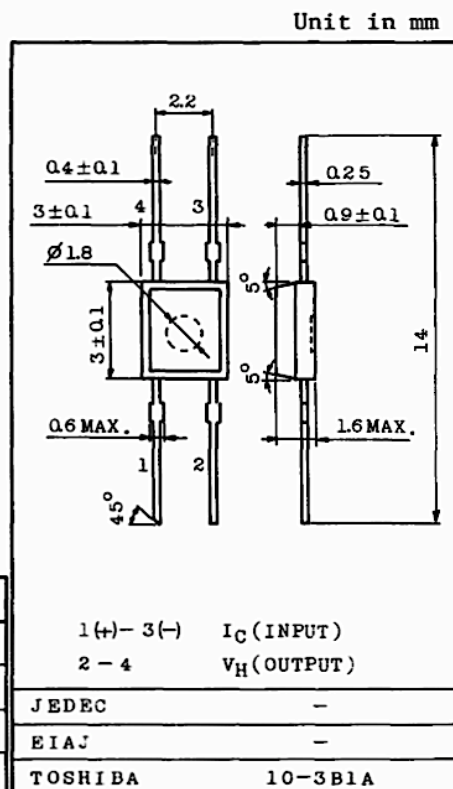
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ENERGY SAVING FOR COOLING FAN MOTOR.
DIGITAL TACHOMETER.
CRANK SHAFT POSITION SENSOR.

FEATURES:

- Excellent Temperature Characteristics.
(; $-55^{\circ}\text{C} \sim +125^{\circ}\text{C}$)
- Wide Operating Temperature Range Capability.
(; up to 15k Gauss)

MAXIMUM RATINGS ($T_a=25^{\circ}\text{C}$)

CHARACTERISTIC	SYMBOL	RATING	UNIT
Control Current (DC)	I_C	10	mA
Control Current (Peak)	I_C	15	mA
Operating Temperature Range	T_{op}	$-55 \sim +125$	$^{\circ}\text{C}$
Storage Temperature Range	T_{stg}	$-55 \sim +150$	$^{\circ}\text{C}$



Weight : 0.045g

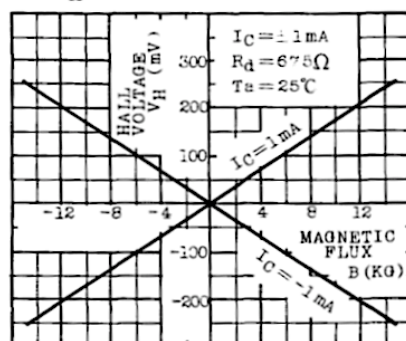
ELECTRICAL CHARACTERISTICS ($T_a=25^{\circ}\text{C}$)

CHARACTERISTIC	SYMBOL	TEST CONDITION	MIN.	TYP.	MAX.	UNIT
Internal Resistance	R_d	$I_C=1\text{mA}$	450	-	900	Ω
Residual Voltage Ratio	V_{HO}/V_H	$I_C=1\text{mA}$, $B=0/B=1\text{KG}$	-	-	± 10	%
Hall Voltage (Note 1)	V_H	$I_C=1\text{mA}$, $B=1\text{KG}$	10	-	30	mV
Temperature Coefficient (Note 2)	V_{HT}	$I_C=1\text{mA}$, $B=5\text{KG}$ $T_1=25^{\circ}\text{C}$, $T_2=125^{\circ}\text{C}$	-	-	-0.06	%/ $^{\circ}\text{C}$
Linearity (Note 3)	ΔK_H	$I_C=1\text{mA}$, $B_1=1\text{KG}$, $B_2=5\text{KG}$	-	-	2	%

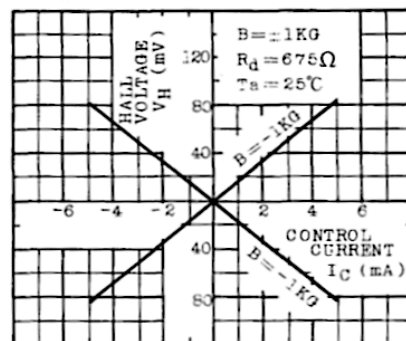
Note 1 : $V_H = V_{HM} - V_{HO}$ (V_{HM} is meter indication)Note 2 : $V_{HT} = \frac{1}{V_H(T_1)} \frac{V_H(T_2) - V_H(T_1)}{T_2 - T_1} \times 100$ (%/ $^{\circ}\text{C}$) V_{HO} : Residual VoltageNote 3 : $\Delta K_H = \frac{K_H(B_2) - K_H(B_1)}{1/2(K_H(B_1) + K_H(B_2))} \times 100$ (%), $K_H = \frac{V_H}{I_C \cdot B}$ K_H : Product Sensitivity

THS102A

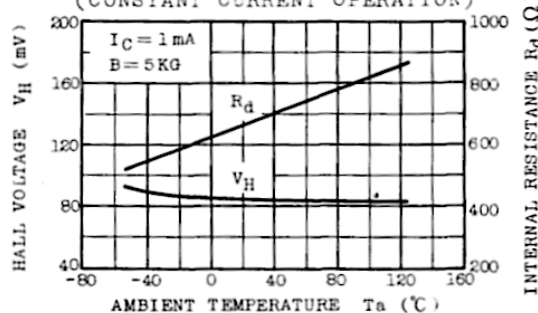
$V_H - B$ CHARACTERISTICS



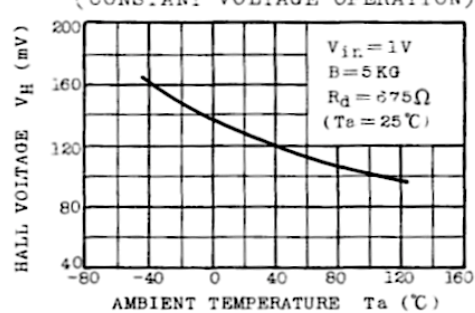
$V_H - I_C$ CHARACTERISTICS



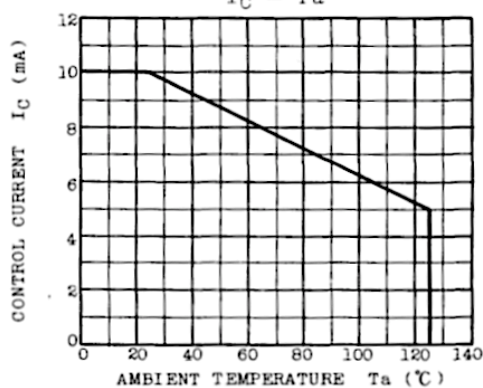
$V_H - T_a, R_d - T_a$ CHARACTERISTICS
(CONSTANT CURRENT OPERATION)



$V_H - T_a$ CHARACTERISTICS
(CONSTANT VOLTAGE OPERATION)



$I_C - T_a$



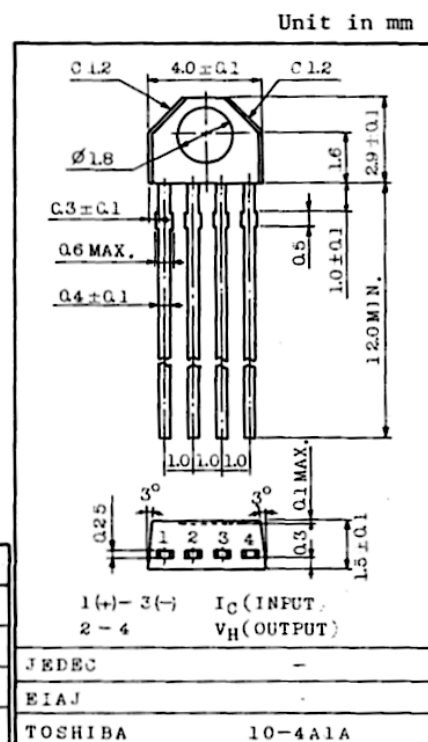
HIGH STABILITY MOTOR CONTROL.
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CRANK SHAT POSITION SENSOR.

FEATURES:

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- Wide Operating Temperature Range Capability.
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- Excellent Output Voltage Linearity.
(; up to 15k Gausses)

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Control Current (DC)	I_C	10	mA
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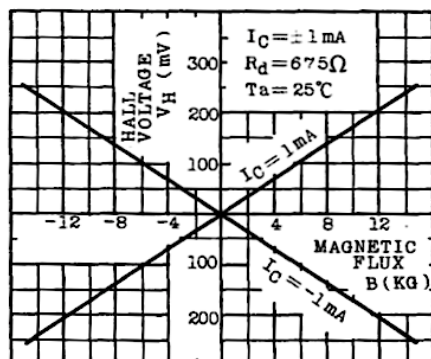
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ELECTRICAL CHARACTERISTICS ($T_a=25^{\circ}\text{C}$)

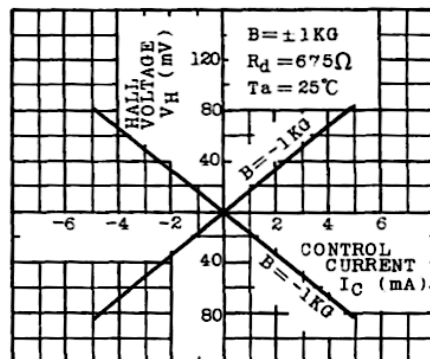
CHARACTERISTIC	SYMBOL	TEST CONDITION	MIN.	TYP.	MAX.	UNIT
Internal Resistance	R_d	$I_C=5\text{mA}$	450	-	900	Ω
Residual Voltage Ratio	V_{HO}/V_H	$I_C=5\text{mA}$, $B=0/B=1\text{KG}$	-	-	± 10	%
Hall Voltage (Note 1)	V_H	$I_C=5\text{mA}$, $B=1\text{KG}$	50	80	120	mV
Temperature Coefficient (Note 2)	V_{HT}	$I_C=5\text{mA}$, $B=5\text{KG}$ $T_1=25^{\circ}\text{C}$, $T_2=125^{\circ}\text{C}$	-	-	-0.06	$\%/^{\circ}\text{C}$
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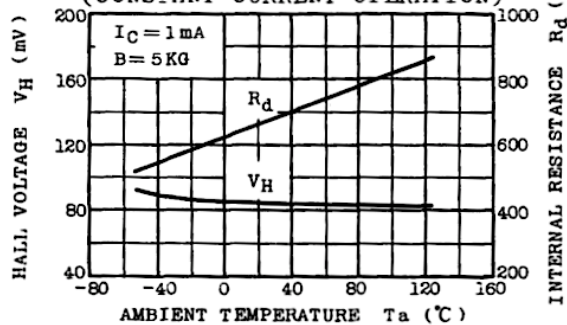
$V_H - B$ CHARACTERISTICS



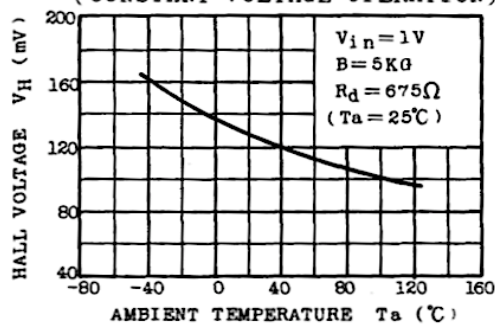
$V_H - I_C$ CHARACTERISTICS



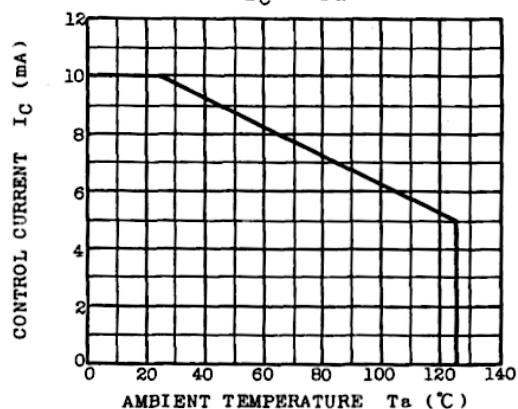
$V_H - T_a, R_d - T_a$ CHARACTERISTICS
(CONSTANT CURRENT OPERATION)



$V_H - T_a$ CHARACTERISTICS
(CONSTANT VOLTAGE OPERATION)



$I_C - T_a$



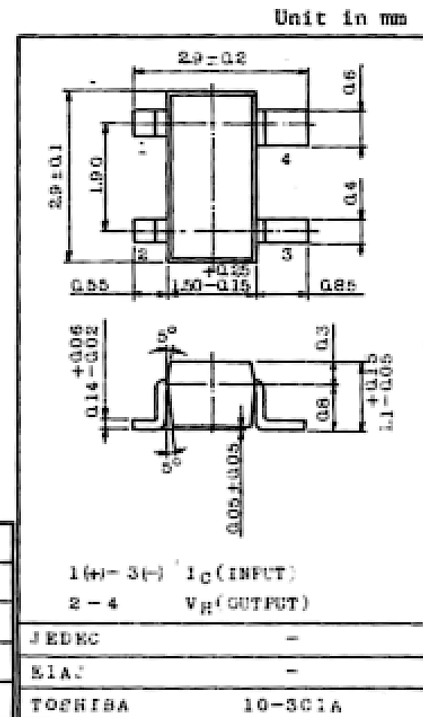
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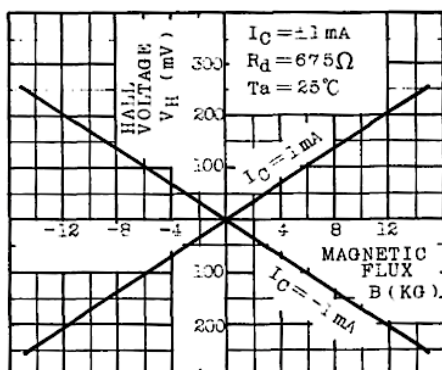
Weight : 0.013g

ELECTRICAL CHARACTERISTICS ($T_a=25^{\circ}\text{C}$)

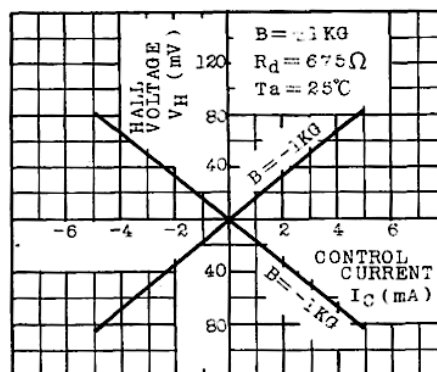
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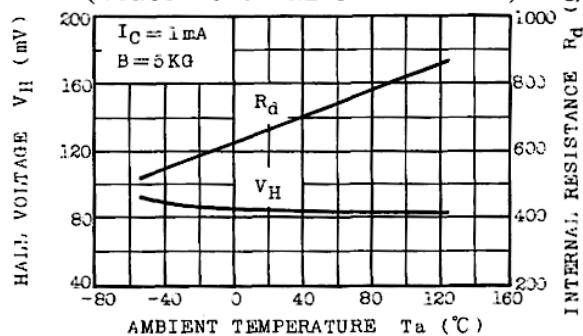
$V_H - B$ CHARACTERISTICS



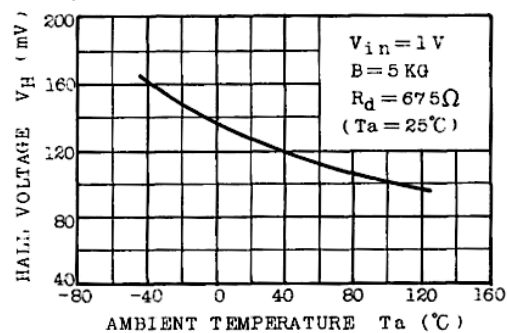
$V_H - I_C$ CHARACTERISTICS



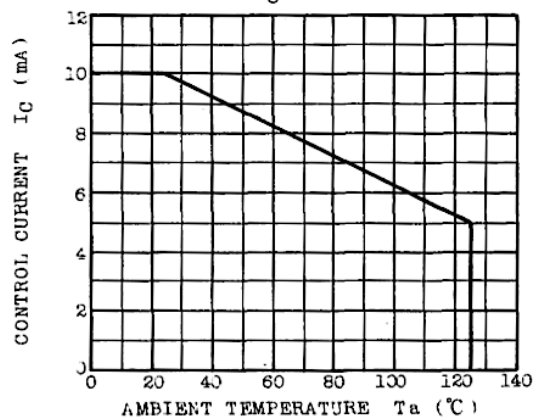
$V_H - T_a, R_d - T_a$ CHARACTERISTICS
(CONSTANT CURRENT OPERATION)



$V_H - T_a$ CHARACTERISTICS
(CONSTANT VOLTAGE OPERATION)



$I_C - T_a$



GaAs Hall sensor

Example circuit using GaAs Hall sensor (Hall motor control)

